Fuel Cell Vehicle Systems Analysis

Fuel Cells for Transportation Program Review
May 9, 2002

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Outline

- Objective
- Approach
- Timeline of Milestones
- Accomplishments
- Addressing Reviewer Comments
- Industry Interactions
- Future Plans
- Summary

Objectives

- Provide DOE and industry with early design insights and modeling tools that lead to introduction and application of advanced technology

- Quantify benefits and impacts of Fuel Cells for Transportation program technology development efforts at the vehicle level

Approach

- Collaborate with industry to populate the model database
- Develop and link to existing component and vehicle models to enhance systems analysis capabilities
- Apply optimization tools to automate analysis process
- Study benefits of fuel cell vehicle design scenarios

Highlights/Milestones

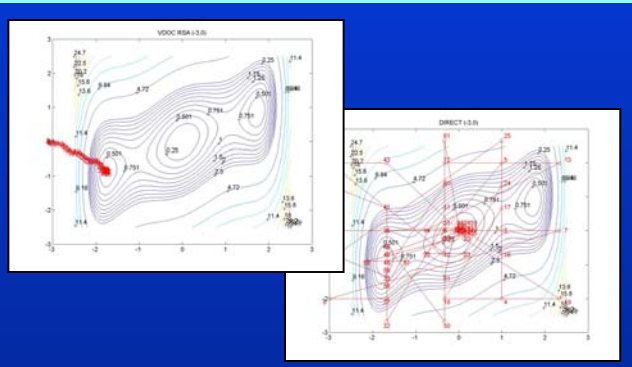
10/01	M	Presented drive cycle impacts study at EVS-18
11/01	M	Presented optimization methods for fuel cell hybrid vehicles at ASME IMECE Conference
2/02		Testing of initial fuel cell thermal systems model from Virginia Tech
4/02		Participated in SAE Fuel Cell Standards Committee
4/02		Initiated data collection effort with web seminar
5/02	M	Incorporation of fuel cell component data into vehicle systems models
6/02		Present fuel cell system characteristics study at FutureCar Congress
7/02	M	Analysis of vehicles using DOE fuel cell technology
8/02	M	Evaluation of technical target based vehicle

M - Completed Milestones

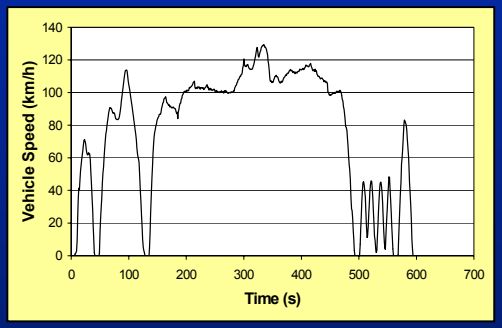
M - Planned Milestones

Accomplishments
Fuel Cell Vehicle Design Optimization

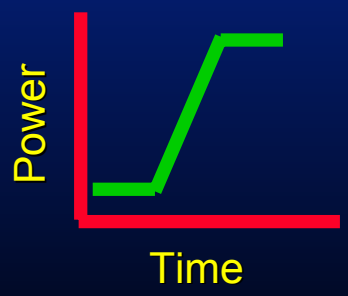
- Optimization Algorithms
  - efficiency of gradient and derivative-free algorithms



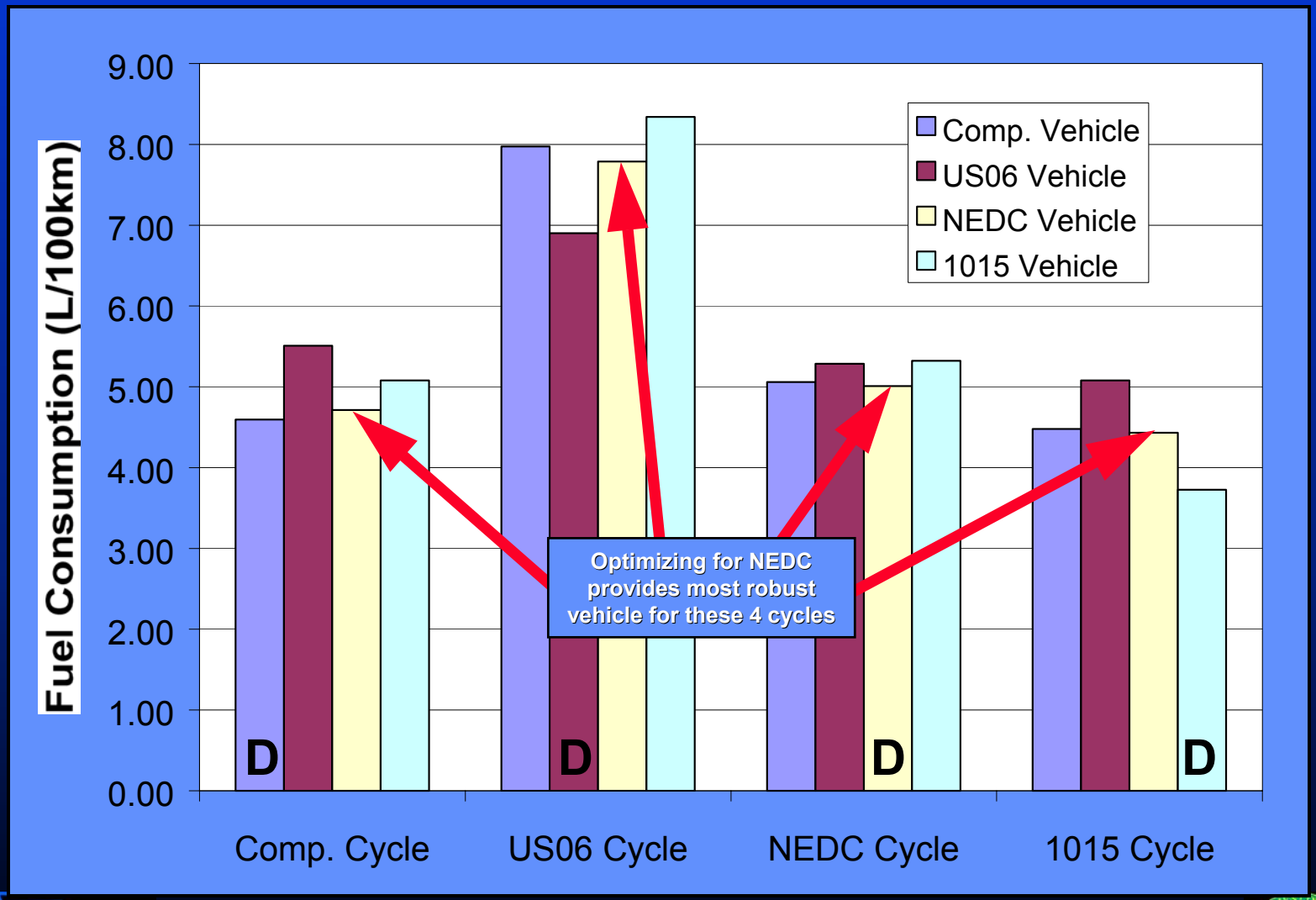
- Drive Cycle Impacts
  - Vehicle optimization for a drive cycle
  - Assessment of robustness of vehicle design



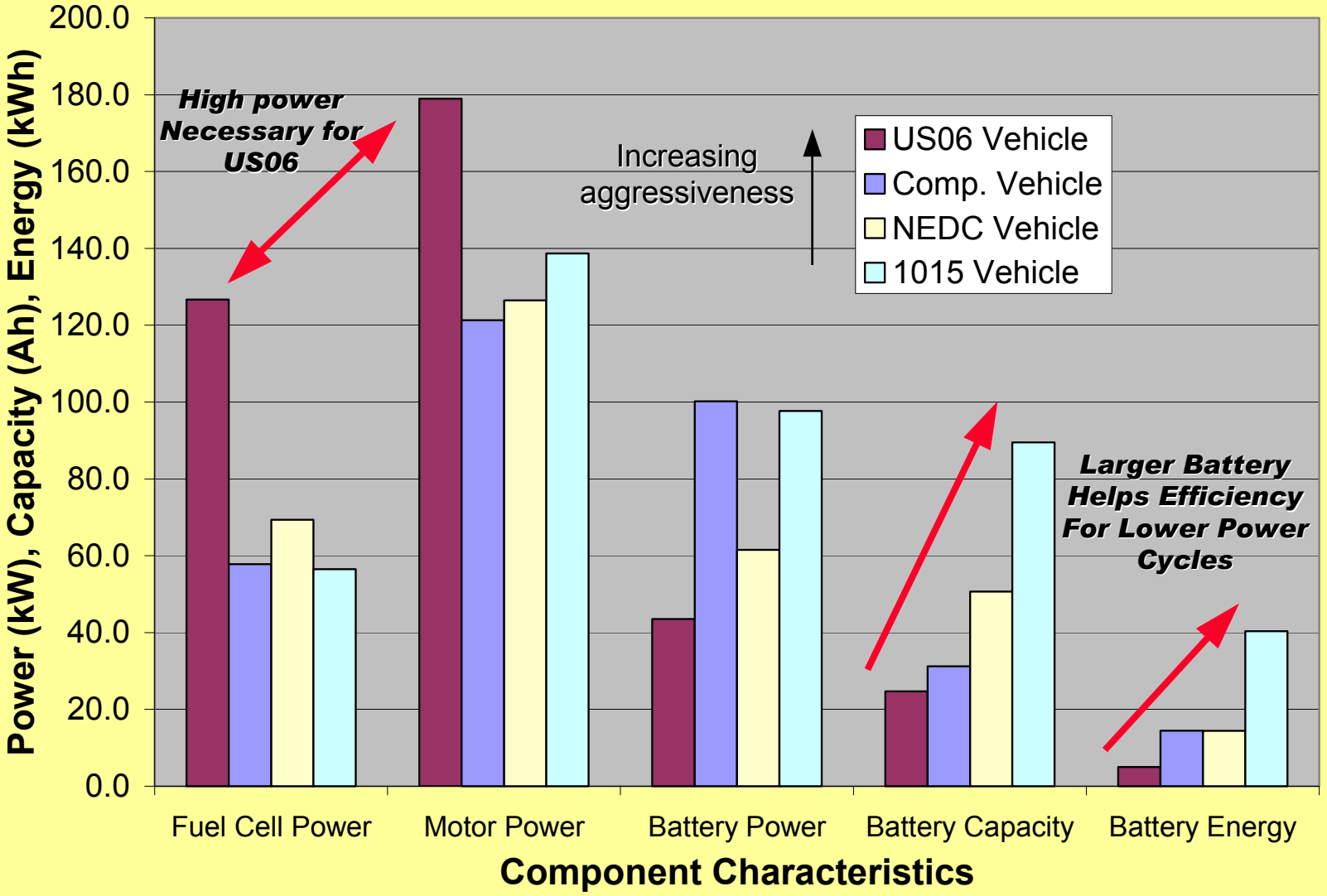
- Fuel Cell Systems Characteristics Impacts
  - Component characteristics drive system design



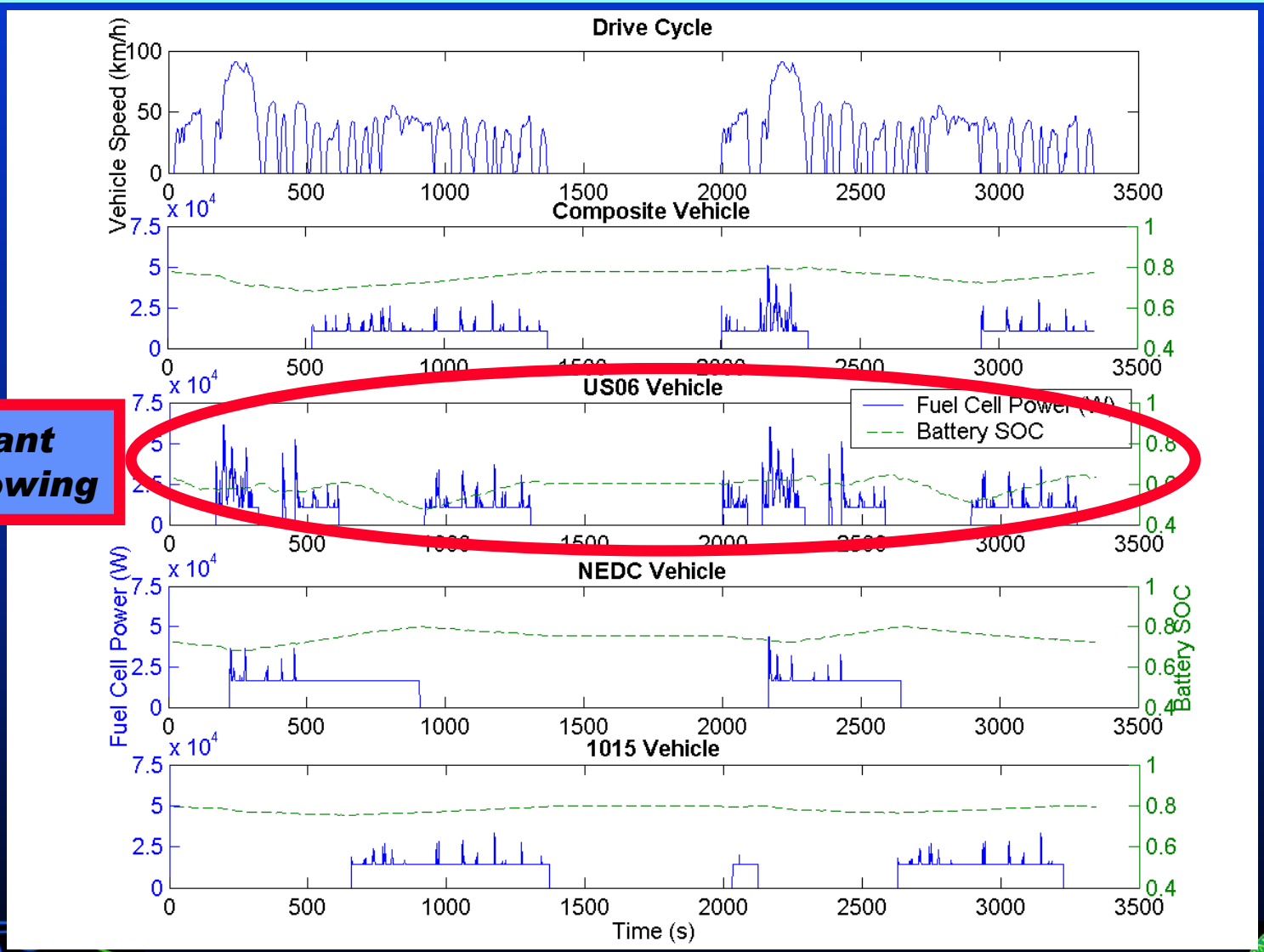
Results: Drive Cycle Investigation (D = vehicle designed for this cycle)



Characteristics of Components for Optimized Vehicles

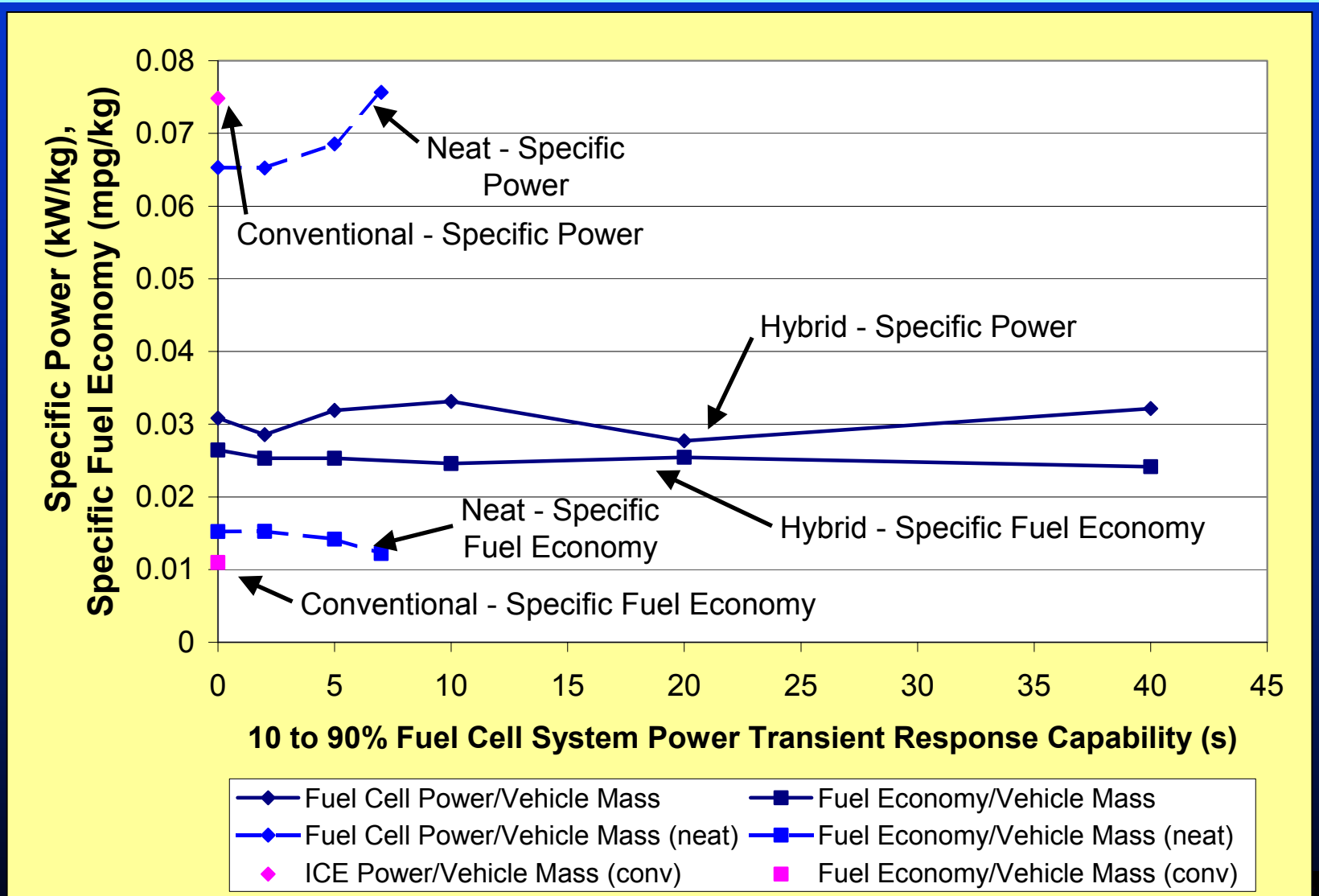


Cycle Operating Characteristics on the 4 Cycles



Significant Load Following

Comparison of Hybrid, Neat, and Conventional Vehicles



Optimization of Fuel Cell Vehicle Design Provides Insight into System Trade-offs

Proceedings of IMECE:
International Mechanical Engineering Congress and Exposition
November 16, 2001 New York, New York

OPTIMIZATION TECHNIQUES FOR HYBRID ELECTRIC VEHICLE ANALYSIS USING ADVISOR

ABSTRACT

Optimizing Energy Management Strategy and Degree of Hybridization for a Hydrogen Fuel Cell SUV

Keith Wipke, Tony Markel, and Doug Nelson

Abstract

2002 - FCC - 24

Vehicle System Impacts of Fuel Cell System Transient Response Capability

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ABSTRACT

The impacts of fuel cell system transient response capability on optimal hybrid and neat fuel cell vehicle configurations have been explored. Vehicle system optimization was performed with the goal of maximizing fuel economy over a drive cycle. Optimal hybrid vehicle designs were derived for fuel cell systems with 10 to 90% power transient response times of 0, 2, 5, 10, 20, and 40 seconds. Optimal neat fuel cell vehicles where generated for responses times of 0, 2, 5, and 7 seconds. DIRECT, a derivative-free optimization algorithm, was used in conjunction with ADVISOR, a vehicle systems analysis tool, to systematically change both powertrain component sizes and the vehicle energy management strategy parameters to provide optimal vehicle system configurations for the range of transient response times.

Results indicate that the transient response time of the fuel cell system significantly influences the preferred powertrain component characteristics and the resulting fuel economy in a neat fuel cell vehicle. Slower transient response capability leads to larger component sizes and lower fuel economy. For a hybrid fuel cell vehicle, optimal combinations of component sizes and energy management strategy parameters can be found that lead to only a minor variation in vehicle fuel economy with respect to fuel cell system transient response capability.

INTRODUCTION

ADVISOR is a vehicle simulator capable of simulating conventional, hybrid electric, electric, and fuel cell vehicles [1, 2]. It uses drivetrain component characteristics to estimate vehicle fuel economy and emissions over defined drive cycles as well as other quantitative performance metrics (i.e., maximum-effort acceleration, gradeability). Roughly 30 different drive cycles and numerous complex test procedures can be used to assess the vehicle fuel economy, emissions, and performance under various simulated test conditions.

Because of the complexity of hybrid electric vehicles (HEVs), including issues such as component sizing, energy management strategy, and battery state-of-charge (SOC) balancing, optimization becomes necessary to give results that can be accurately compared with other vehicles. ADVISOR executes quickly, allowing a single drive cycle (~1000 seconds) to be run on the order of 20 seconds on a standard PC. It is well suited to being linked to optimization routines which may need to evaluate several thousand designs to determine the best.

ADVISOR v3.1 was used in this study as the 'objective function' call within the MATLAB environment. Various optimization algorithms have been linked to ADVISOR to both understand the differences in their approach and their effectiveness in satisfying the needs of finding optimal solutions in the challenging design space of hybrid electric vehicles [3]. It was concluded that the non-gradient based methods of the DIRECT algorithm were extremely effective in finding the regions likely to contain local and possibly global optimum solutions, but required considerable amount of solution time to converge onto the answer within a small tolerance.

Previous work relating to optimization of hybrid vehicles has included efforts at University of California, Davis [4] that examined whether, and under which conditions, hybridization of a fuel cell vehicle would be beneficial. More recently, collaborative work was performed with Virginia Polytechnic Institute and State University (Virginia Tech) on sizing of components for fuel cell hybrids, which this work will build upon [5]. Atwood, et. al. concluded that some level of fuel cell system hybridization was beneficial to the design. Based on a revision to their published results, it was shown that the best City/Highway fuel economy could be obtained at a fuel cell to total power (fuel cell + battery) ratio of 0.26. This translated to a fuel cell providing a net peak power of 52 kW and a 150 kW battery pack for a GMC Suburban vehicle (a total of 202 kW was required to meet the performance requirements). An assumption of this study was that the vehicle mass will remain constant

- Determined that derivative-free optimization algorithms necessary for complex design space of HEVs
- Drive cycle influences optimal degree of hybridization and control parameters
  - NEDC provides robust design
- Fuel cell transient response capability critical for neat fuel cell vehicle
- An optimized hybrid design can nullify the effects of fuel cell transient response

Progress on Data Collection
Key Industry Partners Involved

porvair fuel cell technology

UTC Fuel Cells
A United Technologies Company

Arthur D Little

AIR PRODUCTS

3M

GRUPPO DE NORA

Honeywell

gti

McDERMOTT

McDermott Technology, Inc.

NUVERA FUEL CELLS

Collaboration will help identify applicability and systems issues early in the R&D process.

Draw Upon All Available Sources to Gather Data and and New Models

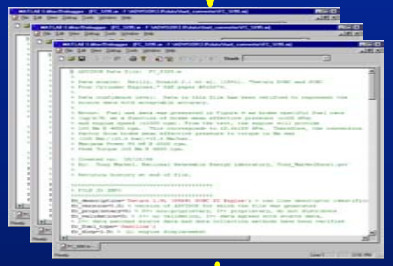
Test Data

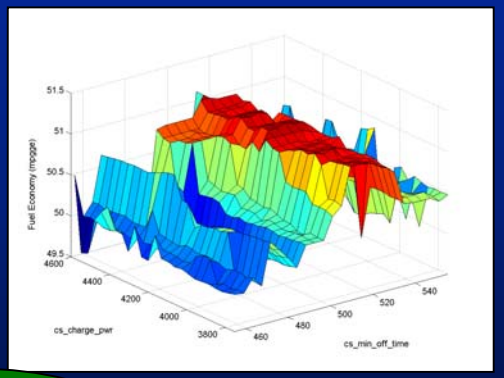
Processing

Modeling

National Labs -- Vehicle Manufacturer's -- Component Suppliers

***** Result *****
Finding solutions to technical barriers!





ADVISOR 3.2
Advanced Vehicle Simulator

+ Optimization

Addressing Reviewer Comments

- Focus on fuel cell system model improvement with lab and industry input for experimental verification of assumptions, conclusions, and results
  - developing partnerships with program contractors that can provide data and feedback on modeling assumptions
- Model validation with experimental data
  - initiated data collection effort to help with model validation and enhancement
- Apply models to analysis questions and disseminate results in peer reviewed setting
  - published three key papers this year discussing fuel cell hybrid vehicle systems analysis

Recent Interactions with Industry

- Creating partnerships with key fuel cell component developers to address technical barriers
- Corresponding with more than 30 entities under contract to DOE to collect data for model validation and systems analysis
- Initiated discussions with Vairex and Opcon Autorotor on air compression systems
- Contributing to development of SAE Code & Standards for fuel cell vehicle testing

Plans and Future Milestones

- Fuel cell hybrid vehicle system optimization
  - Using ultra-capacitors, and other storage technologies
  - Investigating fuel cell idle rather than shut-down
  - Technology application to multiple platforms
- Data collection and systems modeling
- Evaluate options for fuel cell system performance enhancement and cost reduction in a vehicle application
- Completion of enhanced fuel cell system thermal model under development at Virginia Tech

Summary

- Vehicle systems tools coupled with optimization are being applied to provide design insights
- Progress has been made to collect data for populating models and validating model results
- Many fuel cell vehicle systems design scenarios yet to be evaluated
- Developing partnerships with industry to provide modeling assumptions review